

Energy dependence of inclusive photon elliptic flow in heavy-ion collision models

Ranbir Singh¹, Md. Nasim², Bedangadas Mohanty² and Sanjeev Singh Sambyal¹

¹ Physics Department, University of Jammu, Jammu 180001, India and ² Variable Energy Cyclotron Centre, Kolkata 700064, India

Abstract. We present a comparison of inclusive photon elliptic flow parameter (v_2) measured at RHIC and SPS high energy heavy-ion collision experiments to calculations done using the AMPT and UrQMD models. The new results discussed includes the comparison of the model calculations of photon v_2 to corresponding measurements at the forward rapidities. We observe that the AMPT model which includes partonic interactions and quark coalescence as a mechanism of hadronization is in good agreement with the measurements even at forward rapidities ($2.3 < \eta < 3.9$) at RHIC as was previously observed for measurements at midrapidity. At the top SPS energy the contribution from partonic effects are smaller than that at RHIC energy, based on the comparison of the measured photon v_2 with those from the AMPT default and UrQMD model calculations. We find that if the measurements in RHIC beam energy scan (BES) and LHC energies would require an energy dependent partonic cross section in the AMPT models, then the observed longitudinal scaling of v_2 at top RHIC energies (19.6–200 GeV) will be violated. We also discuss the relation between the inclusive photon v_2 and those of their parent π^0 's for the beam energies of 7.7 GeV to 2.76 TeV. The model results show that the transverse momentum (p_T) integrated v_2 of π^0 is larger by about 44% relative to those of the inclusive photons. Finally we present the expectations of inclusive photon v_2 for the RHIC beam energy scan (BES) program and LHC from the transport models, so that they can be compared to corresponding measurements using the data already collected at RHIC and LHC.

1. Introduction

Elliptic flow (v_2) measurements are believed to provide information on the dynamics of the system formed in the heavy-ion collisions [1, 2]. Within the framework of a hydrodynamical approach, v_2 is found to be sensitive to the equation of state of the system formed in the collisions [3]. Measurements of elliptic flow at the forward rapidity have revealed an interesting observation of longitudinal scaling of v_2 when plotted as a function of pseudorapidity (η) shifted by the beam rapidity (y_{beam}) [4, 5]. With the upcoming new measurements in the beam energy scan (BES) program at RHIC [6] and higher energies at LHC, this scaling can be put to a further test. At rapidities where these measurements are essential for studying such scaling at RHIC and LHC we have mostly multiplicity detectors in both the colliders. For example, in STAR experiment and ALICE there exists a photon multiplicity detector (PMD) in the range $2.3 < \eta < 3.9$ [7, 8]. In fact the azimuthal anisotropy measurements using photons measured in PMD for S+Au collisions at 200 AGeV were the first observation of collectivity at SPS energies [9]. In this paper we concentrate on the v_2 of inclusive photons measured by such a detector and discuss the limitations and possibilities it could offer to understand the longitudinal scaling of v_2 in BES and LHC energies.

The v_2 is the 2nd Fourier coefficient of the particle azimuthal angle (ϕ) distribution with respect to the reaction plane angle (Ψ). Where the Ψ is the angle subtended by the plane containing the impact parameter vector and the beam direction (usually considered as the Z-axis) with the X-axis [10]. Mathematically we can write,

$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos(2(\phi - \Psi)). \quad (1)$$

For a given rapidity/centrality window the second coefficient or the elliptic flow parameter is

$$v_2 = \langle \cos(2(\phi - \Psi)) \rangle. \quad (2)$$

We present a study of the v_2 for inclusive photon using above approach of measurement from transport models in heavy-ion collisions like Ultra relativistic Quantum Molecular Dynamics (UrQMD) [11] and A Multi Phase Transport (AMPT) model [12]. Since more than 90% of the inclusive photons come from the decay of π^0 mesons, we will first study how the decay effect decreases the measured v_2 for photons relative to those of the parent π^0 . PMD like detectors have limitations in the form of finite particle counting efficiency and also the purity of the photon sample [13]. We will discuss the effect of these on the measured v_2 . There already exists measurements of v_2 of inclusive photons at SPS by the WA98 experiment [14] and at RHIC by the STAR experiment [15] and PHENIX experiment [16]. Using two different approaches in the AMPT model: AMPT default and AMPT string melting (AMPT-SM), we will discuss the relevance of partonic interactions and partonic coalescence as a mechanism of hadronization to inclusive photon v_2 measurements in the above experiments. The models are also used to predict the magnitude of v_2 expected at RHIC BES and LHC energies.

Before we proceed further, we discuss very briefly the main features of the two models, the results of which are discussed in this paper. The UrQMD model is based on a microscopic transport theory where the phase space description of the reactions play an important role. The hadrons propagate on a classical trajectory undergoing stochastic binary scattering, color string formation and resonance decay. The model incorporates baryon-baryon, meson-baryon and meson-meson interactions. The v_2 obtained from the UrQMD model will provide information on the contribution from the hadronic interactions. The AMPT model uses the same initial conditions as in Heavy Ion Jet Ion Interaction Generator (HIJING) [17]. Then the mini-jet partons are made to undergo scattering before they are allowed to fragment into hadrons. The string melting (SM) version of the AMPT model is based on the idea that for energy densities beyond a critical value of about $1 \text{ GeV}/fm^3$, it is difficult to visualize the coexistence of strings (or hadrons) and partons. Hence the need to melt the strings to partons. This is done by converting the mesons to a quark and anti-quark pair, baryons to three quarks (through intermediate diquark process) etc. The scattering of the quarks are based on parton cascade ZPC [12]. Once the interactions stop, the partons then hadronizes through the mechanism of parton coalescence. The interactions between the mini-jet partons in AMPT model and those between partons in the AMPT-SM model could give rise to a substantial v_2 . The results from AMPT-SM would indicate the contribution of partonic interactions to the observed v_2 . Recently it has been shown that while a parton-parton interaction cross section of 10 mb is needed to explain the observed v_2 at midrapidity for top RHIC energies, a much smaller cross section of 1.5 mb is required to explain the observed v_2 at midrapidity for the LHC energies [18]. Hence it will be interesting to see what happens to the longitudinal scaling of v_2 if the requirement of parton-parton cross section changes as a function of center of mass energy ($\sqrt{s_{NN}}$). In this paper we have generated events using the UrQMD (ver.2.3) and AMPT (ver. 1.25t3) (with HIJING (ver. 1.35)) event generators at various beam energies results of which are presented in this paper. The default conditions are used, For RHIC energies the parton-parton cross section in AMPT-SM is taken to be 10 mb and for the LHC energy it is taken as 1.5 mb.

The paper is organized as follows. In the next section we show a comparison between v_2 of inclusive photon and π^0 as a function of p_T , η and collision centrality. The energy dependence of the difference in v_2 of inclusive photon to those from π^0 are also discussed. Then we present a brief discussion on the effect of finite efficiency and purity of photon counting on inclusive photon v_2 measurements using a simple model based approach. In section III we compare the inclusive photon measurements at SPS and RHIC energies to results from UrQMD and AMPT models. In section IV we present the expectations of inclusive photon v_2 at RHIC BES and LHC energies. In the end of the section we provide a discussion on longitudinal scaling of inclusive photon v_2 . Finally we summarize our study in section V.

2. photon versus neutral pion v_2 at RHIC and LHC

About 90% of the inclusive photon come from decay of π^0 mesons [13]. In this section we discuss how the v_2 of photons and π^0 compares as a function of collision centrality, p_T and η at $\sqrt{s_{NN}} = 2.76$ TeV (chosen as a representative case) for Pb+Pb collisions at forward rapidity ($2.3 < \eta < 3.9$). We discuss the results at forward rapidity as in this region the actual measurements will be carried out in the experiments. We study the effect using AMPT model with two versions - default and SM.

Figure 1 shows the comparison of v_2 for photons and π^0 . The Fig. 1a shows the results as a function of p_T . We see that for both AMPT-SM and AMPT default the v_2 for photons and π^0 are comparable for minimum bias Pb+Pb collisions. The magnitude of v_2 from AMPT-SM is higher than that from AMPT-default. The Fig. 1b shows the v_2 as a function of η . The p_T integrated v_2 of photon is smaller than that for π^0 for minimum bias Pb+Pb collisions. The Fig. 1c shows the results as a function of collision centrality denoted by % cross section. The collision centrality could very well be denoted by the number of participating nucleons (N_{part}), calculated commonly using Glauber Model. The nucleon-nucleon cross sections are 42 and 65 mb for $\sqrt{s_{NN}} = 200$ GeV and 2.76 TeV respectively. At $\sqrt{s_{NN}} = 2.76$ TeV for Pb+Pb collisions, typically 0-5%, 5-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80% cross section have the corresponding average N_{part} values as 382 ± 3 , 330 ± 4 , 260 ± 4 , 186 ± 4 , 129 ± 3 , 85 ± 3 , 53 ± 2 , 30 ± 1 , 16 ± 1 respectively. While for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, the 0-5%, 5-10%, 10-20%, 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, 70-80% cross section have the corresponding average N_{part} values as 350 ± 3 , 301 ± 7 , 236 ± 8 , 168 ± 10 , 116 ± 11 , 76 ± 10 , 48 ± 9 , 28 ± 7 , 14 ± 5 respectively. As seen in the case for η dependence, the p_T integrated v_2 in the $2.3 < \eta < 2.9$ for photons are found to be smaller than π^0 . Both models display the expected trends of v_2 as a function of centrality, with v_2 being smaller for central collisions. The lower value of p_T integrated v_2 of photon compared to those for π^0 although $v_2(p_T)$ are comparable is due to photon p_T spectra having a smaller mean transverse momentum compared to corresponding value for π^0 . So for a multiplicity detector as in STAR or ALICE experiments, without possibility of having p_T information, the measured photon v_2 would reflect a lower value than expected from the parent π^0 . Similar conclusions are observed for other energies (results from which are presented below) we have studied and so not discussed in detail. Also shown in Fig. 1c are the results of inclusive charged hadron v_2 using 4-particle cumulant method at midrapidity for Pb+Pb collision at $\sqrt{s_{NN}} = 2.76$ TeV from the ALICE experiment [19]. The inclusive charged hadron v_2 values at midrapidity are more than a factor 2 higher than the values of v_2 from inclusive photon of π^0 calculated using models at the forward rapidity. These results suggest that one could expect a distinct rapidity dependence of v_2 at LHC energies, with the v_2 values starting to decrease before or around $\eta = 2.3$ units.

Figure 2 shows the difference in v_2 of π^0 compared to those from the photons divided by the v_2 of photons as a function of beam energy from AMPT SM model using minimum bias collisions within $2.3 < \eta < 2.9$. This relative fraction is observed

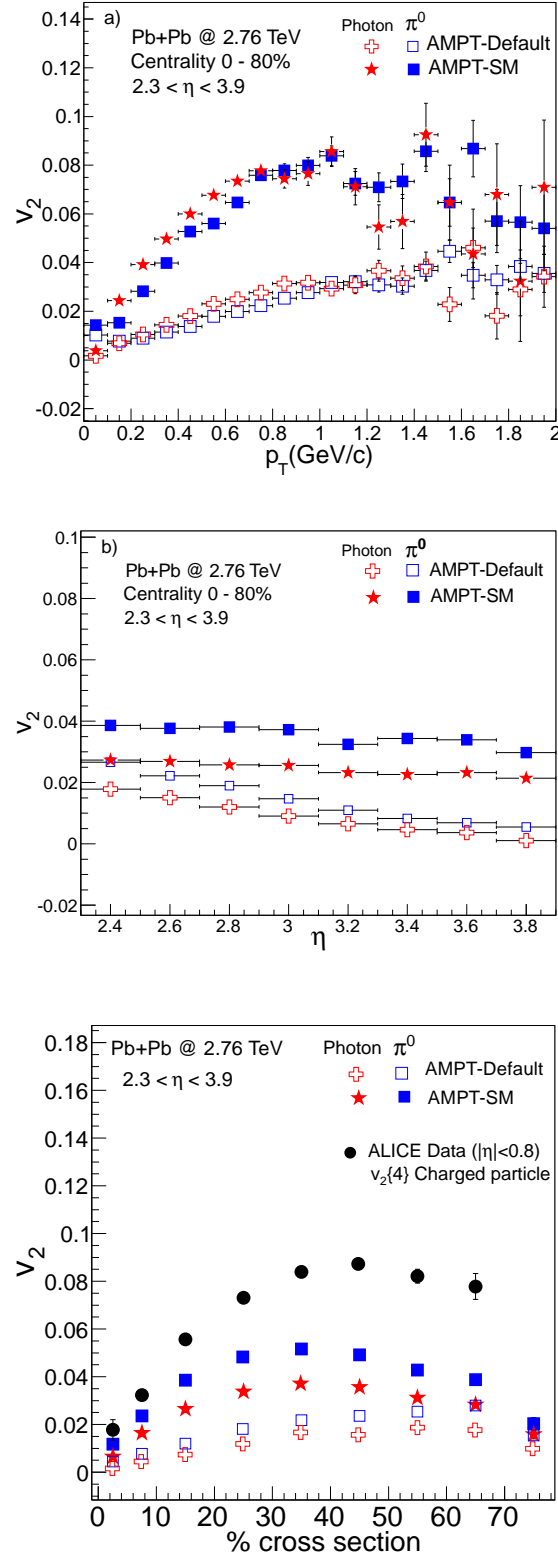


Figure 1. (Color online) Elliptic flow (v_2) as a function p_T (a), η (b) and % cross section (c) for inclusive photon and π^0 from AMPT-default and AMPT-SM in 0-80% Pb+Pb collisions for $2.3 < \eta < 3.9$ at $\sqrt{s_{NN}} = 2.76$ TeV. Also shown are the v_2 results obtained from 4-particle cumulant method for the inclusive charged hadrons from the ALICE experiment [19] at midrapidity for comparison. It may be noted that the maximum value of p_T integrated v_2 at midrapidity for charged hadrons for Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is $0.087 + 0.002$ (stat.) + 0.003 (svst) [19].

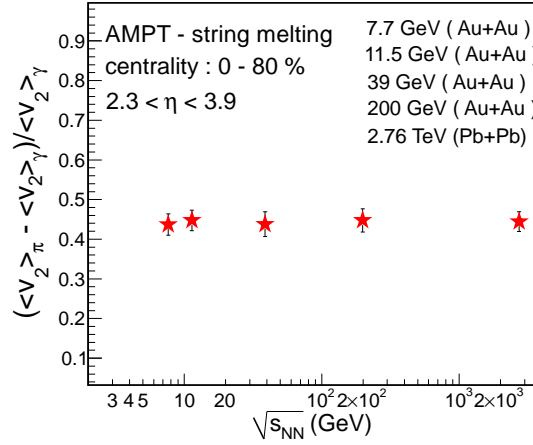


Figure 2. (Color online) Ratio of the difference in average elliptic flow ($\langle v_2 \rangle$) for π^0 and inclusive photon to the $\langle v_2 \rangle$ of photons as a function of beam energy. The results as shown for 0-80% nucleus-nucleus collisions for $2.3 < \eta < 3.9$ using AMPT-SM model.

to be almost constant as a function of $\sqrt{s_{NN}}$ and has a value of around 0.44. Similar conclusions are observed from other transport models like AMPT-default and UrQMD and hence not presented here.

The photon multiplicity detectors are affected by finite efficiency of photon counting and purity of the detected photon sample. We have estimated the effect of this on the measured v_2 of photons. For studying the effect of efficiency, we have randomly removed photons from an event in the measured η range by a factor which depends on the photon counting efficiency. The photon counting efficiency is defined as the ratio of the final number of photons detected to the initial number of photons in an event. This number is varied from 30% to 95% to see the effect on v_2 . The results are shown in Fig. 3. We observe that the change in efficiency does not affect the measured v_2 . The typical value of efficiency for a realistic PMD is about 60% [13]. From v_2 measurement perspective this is a trivial result as long as the efficiency does not have a azimuthal angle dependence.

The purity of the photon sample in multiplicity detectors are dominantly affected by charged particles mimicking a photon signal. They are usually reduced by applying certain thresholds on the signal deposited. Here the effect is studied by adding a certain number of charged hadrons to the photon sample, yet maintaining the same number of initial photons in an event. The number to be added is called as the contamination and is related to the purity as $(1 - \text{purity})$. Where purity is defined as the ratio of number of photons in an events to total number of photons and charged particles considered as photons in the event. The results are shown in Fig. 3. One observes that the purity affects the measured v_2 of photons significantly. The measured v_2 increases relative to the photon v_2 as the purity of the photon sample decreases. Hence it is suggested that for photon v_2 measurements in experiments, stability of the results needs to be checked by varying the thresholds used to discriminate photon and hadrons falling on the detector.

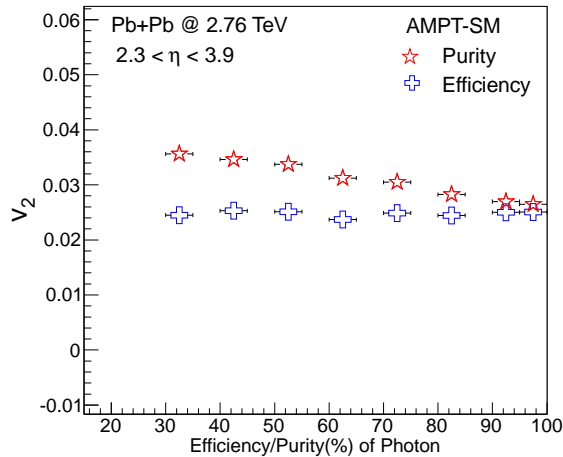


Figure 3. (Color online) v_2 of inclusive photon as a function of photon counting efficiency and purity (in %) using AMPT-SM in 0-80% Pb+Pb collisions for $2.3 < \eta < 3.9$ at $\sqrt{s_{NN}} = 2.76$ TeV.

Further in the experiments a detailed simulation using realistic detector configurations can be used to understand the effects. Typical values of purity encountered is around 60-70% [7, 8, 14], which as per the present study, could lead to a difference in actual and measured v_2 of the order of 15%.

3. Comparison of photon v_2 measurements at SPS and RHIC to models

In this section we compare the inclusive photon v_2 measurements to three different transport model calculations. While AMPT default and UrQMD does not include any partonic effects, AMPT-SM includes such a contribution. The difference between AMPT default and UrQMD could lie in the treatment of initial and final state re-scattering effects. A comparison of data with results from AMPT default and UrQMD relative to those from AMPT-SM will help us to understand the contribution to v_2 from partonic effects. The comparison of data with results from AMPT default and UrQMD will help understand the role of re-scattering. Further we discuss the effect of partonic cross section on v_2 measurements by choosing their values to be 3, 6 and 10 mb in AMPT-SM model and comparing the results to existing inclusive photon v_2 measurements at SPS and RHIC energies. With a factor of 10 difference in beam energy, one would naively expect different partonic cross section for SPS and RHIC energies which gives the best agreement with the measured v_2 .

Figure 4 shows the comparison of v_2 of inclusive photon as a function of average number of participating nucleons and p_T for three different centrality classes in Pb+Pb collisions at $E_{lab} = 158$ AGeV measured by the WA98 experiment [14] at CERN SPS to various transport model results. The centrality dependence results are obtained using a photon multiplicity detector while the p_T dependence results were obtained from a

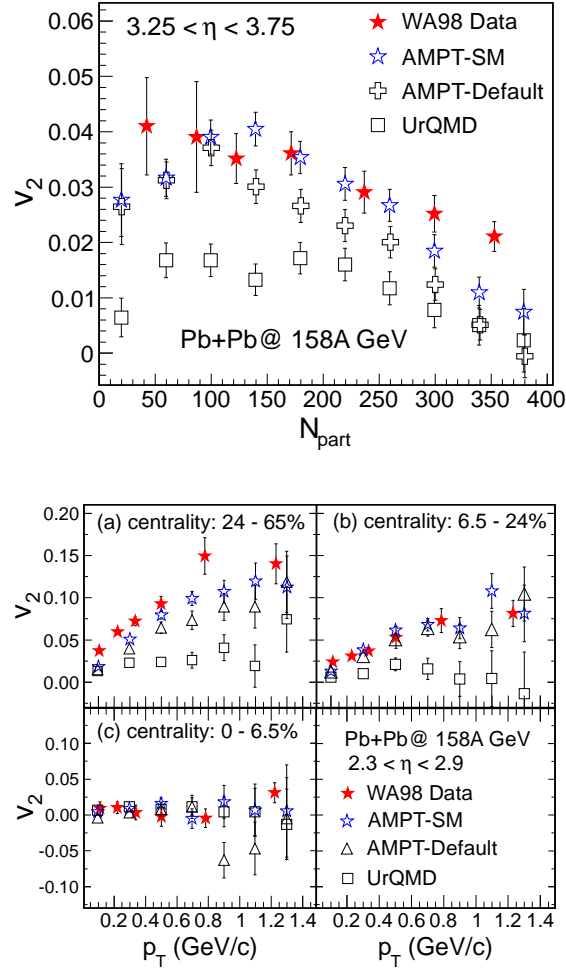


Figure 4. (Color online) Upper panel: v_2 of inclusive photon as a function of collision centrality for Pb+Pb collisions at laboratory energy of 158 AGeV as measured by the photon multiplicity detector in WA98 experiment [14]. The results are compared to corresponding values from AMPT-SM, AMPT default and UrQMD models. Lower panel: v_2 of inclusive photon as a function of p_T for three collision centrality as measured by the Pb-Glass Calorimeter in WA98 experiment [14]. The results are compared to the three transport model calculations as mentioned above.

Lead-glass calorimeter. The error bars includes the systematic uncertainties, including the estimated effect of charged hadron contamination to the measurements. We observe that for this SPS top beam energy, in general, $v_2(\text{UrQMD}) < v_2(\text{AMPT-default}) < v_2(\text{AMPT-SM})$. The results from AMPT-SM having the closest agreement with the measurements both as a function of collision centrality and p_T . However the results from default version, which does not include partonic effects are also not far off.

Figure 5 shows the comparison of preliminary result on v_2 of inclusive photon as a function of collision centrality measured by the STAR experiment at $\sqrt{s_{NN}} = 200$ GeV using a photon multiplicity detector [15] to various transport model results. While

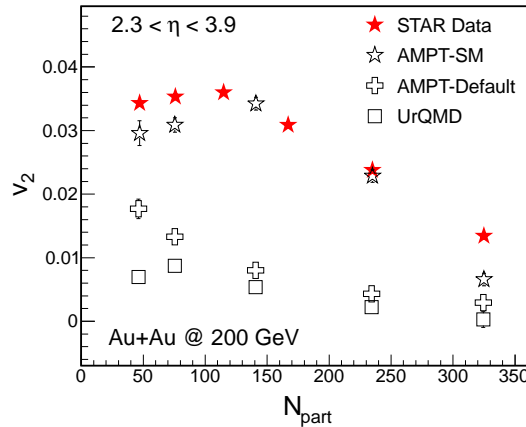


Figure 5. (Color online) Preliminary v_2 of inclusive photon as a function of collision centrality measured by the photon multiplicity detector in STAR experiment at RHIC for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [15]. The results are compared to transport model calculations using AMPT-SM, AMPT default and UrQMD models.

the v_2 from AMPT default and UrQMD are comparable to each other, the v_2 from AMPT-SM is much higher and comparable to the experimental measurements. This clearly shows that even at forward rapidity in RHIC a substantial contribution of the measured v_2 could be due to partonic interactions. Similar conclusions were derived from the midrapidity measurements from inclusive charged particle v_2 . However the model comparison to top SPS energies results as shown in Fig. 4 indicates that the partonic contribution to v_2 is small relative to the case for RHIC. It may be noted that the AMPT default and UrQMD results for RHIC energy as shown in Fig. 5 are comparable while those for the SPS energy are different. This could be due to the different center of mass rapidity range of the measurements. The SPS results are close to midrapidity in the center of mass system while those for the RHIC are at forward rapidity.

Figure 6 shows the comparison of the centrality dependence of inclusive photon v_2 measured at SPS and RHIC to the results from the AMPT-SM model with three different partonic cross sections of 3, 6 and 10 mb. We find that the v_2 values from the AMPT-SM model calculations increases with increase in the value of the partonic cross section used for both at SPS and RHIC energies. The data at both the energies seems to favor a large partonic cross section of 10 mb. Due to the possibility of change in the systems composition and the access to different phases (QGP or hadronic) with change in beam energy, one would have expected the data at RHIC and SPS to favor a different partonic cross section. However it must be noted that while the results at SPS are close to the midrapidity range in the center of mass frame, those at RHIC are at forward rapidity. It has been that several bulk properties of matter at forward rapidity at RHIC is similar to those at midrapidity at SPS [20]. New data from the RHIC BES program at lower energies and higher LHC energies or in wide rapidity range will help

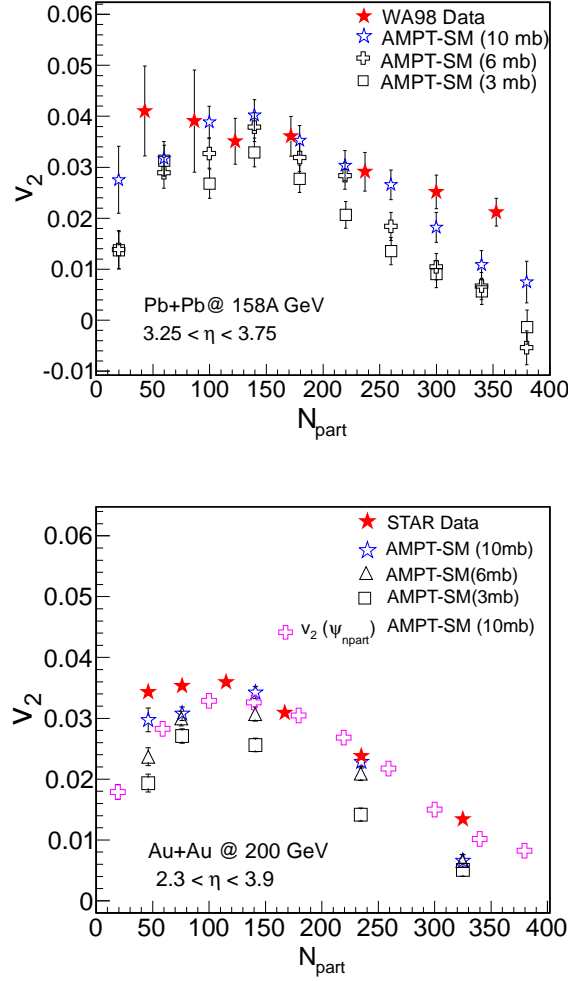


Figure 6. (Color online) Upper panel: v_2 of inclusive photon as a function of collision centrality for Pb+Pb collisions at laboratory energy of 158 AGeV as measured by the photon multiplicity detector in WA98 experiment [14]. The results are compared to corresponding values from AMPT-SM with three different values of partonic cross sections. Lower panel: Preliminary v_2 of inclusive photon as a function of collision centrality measured by the photon multiplicity detector in STAR experiment at RHIC for Au+Au collisions at $\sqrt{s_{\text{NN}}} = 200$ GeV [15]. The results are compared to AMPT-SM model calculations with three different values of partonic cross section. The value of v_2 with respect to participant plane Ψ_{npart} from AMPT-SM model is also shown to indicate the effect of flow fluctuations.

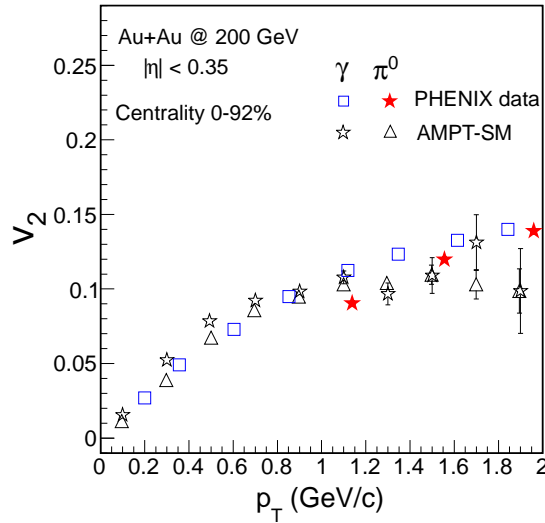


Figure 7. (Color online) Inclusive photon and π^0 v_2 as a function p_T at midrapidity for minimum bias Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [16]. The results are compared to AMPT-SM model calculations.

in studying the sensitivity of the measurements to change in partonic cross section used in transport model calculations.

Also shown in the Fig 6 for RHIC energies are the AMPT-SM calculation of v_2 using the participant plane (Ψ_{npart}). The other model calculations uses the standard reaction plane (Ψ). One observes that the v_2 for central collisions obtained using participant plane from the model calculation are larger than the corresponding values obtained using the reaction plane. The agreement with the measurements are much better for the central collisions for v_2 obtained using Ψ_{npart} . The v_2 calculated using reaction plane neglected the contributions from flow fluctuations [21]. It may also be noted that AMPT model calculations failed to explain the identified hadron v_2 at RHIC energies [12].

Figure 7 shows the inclusive photon and π^0 v_2 as a function of p_T measured by PHENIX collaboration for Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at midrapidity ($|\eta| < 0.35$) for minimum bias collisions. We have compared the data to calculations from AMPT-SM model. We observe good agreement between the data and model results with calculations done using parton cross section of 10 mb. Both the mid rapidity and forward rapidity RHIC results suggest that the data favors a large partonic cross section of 10 mb.

4. Expectation of photon v_2 at RHIC Beam Energy Scan Program and LHC

RHIC has recently complete a Beam Energy Scan (BES) program, by collecting data for the $\sqrt{s_{NN}} = 7.7 - 200$ GeV, in the year 2010-2011 [6]. The main goal of the program is to study the structure of the QCD phase diagram [22]. Photon v_2 measurements

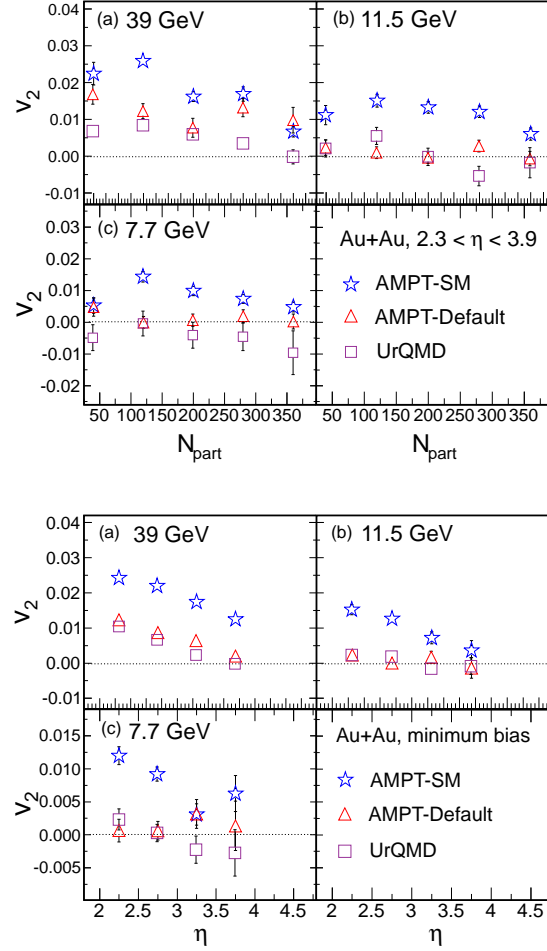


Figure 8. (Color online) Expectation of inclusive photon v_2 as a function collision centrality and η (range where the measurements will be carried out in actual experiment) for $\sqrt{s_{NN}} = 7.7, 11.5$ and 39 GeV Au+Au collisions using AMPT-SM, AMPT default and UrQMD models.

at forward rapidities in this program together with those at forward rapidity will provide information on the longitudinal scaling of v_2 . It may be mentioned that photon multiplicity measurements at RHIC were used to study for the first time identified particle longitudinal scaling behavior of the multiplicity distributions [13]. The longitudinal scaling for inclusive charged particles were earlier reported by PHOBOS [23] and BRAHMS [24] experiments at RHIC.

Figure 8 shows the inclusive photon v_2 expected from transport models at the BES energies of 7.7, 11.5 and 39 GeV as a function of collision centrality and pseudorapidity range where such measurements are possible in the experiment. Not much difference is observed between the v_2 from AMPT default and UrQMD at these energies, while the AMPT-SM results are significantly higher. These results can be compared to data when available to understand the transition energy from partonic to pure hadronic interaction

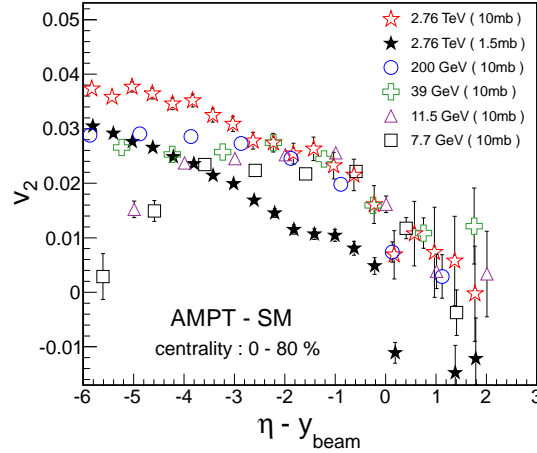


Figure 9. (Color online) Inclusive photon v_2 as a function $\eta - y_{\text{beam}}$ for Au+Au collisions at $\sqrt{s_{\text{NN}}} = 7.7, 11.5, 39$ and 200 GeV with parton cross section of 10 mb and Pb+Pb collisions at $\sqrt{s_{\text{NN}}} = 2.76$ TeV for parton cross section of 1.5 and 10 mb. The results are shown for 0 - 80% collision centrality.

as the dominant source of v_2 [25]. The expected decrease in v_2 as the collision become more central or the η increases is observed for all the beam energies. Although at $\sqrt{s_{\text{NN}}} = 7.7$ and 11.5 GeV AMPT-default and UrQMD predicts a negligible v_2 for the inclusive photon.

Figure 9 shows the v_2 for inclusive photon as a function $\eta - y_{\text{beam}}$ for $\sqrt{s_{\text{NN}}} = 7.7$ GeV to 2.76 TeV using AMPT-SM with default settings. The parton cross section is taken as 10 mb. We observe the usual longitudinal scaling of v_2 . We do not present the results for the other models (AMPT-default and UrQMD) as those models have been shown not to exhibit the longitudinal scaling behavior for v_2 [5]. Recently it was shown that although the results with a partonic cross section of 10 mb in AMPT-SM at RHIC is able to explain the measured distributions, for those at LHC energies one requires a smaller cross section of 1.5 mb. In Fig. 9 we also show the v_2 vs. $\eta - y_{\text{beam}}$ from AMPT-SM using cross section of 1.5 mb at $\sqrt{s_{\text{NN}}} = 2.76$ TeV. We find the longitudinal scaling behavior is violated. If the collisions at lower and higher energies require different cross sections for explaining the measured distributions, we would expect a breakdown of the longitudinal scaling. The photon v_2 measurements at RHIC BES and LHC are crucial for verifying this conclusion.

5. Summary

Keeping in mind the near future measurements of inclusive photon v_2 in RHIC BES and LHC programs, we have presented a transport model (UrQMD and AMPT) based discussion on various expectations from such a measurement. We find that although the p_T dependence of v_2 of inclusive photon in the transport models is similar to those for

the π^0 (90% of the inclusive photon are from π^0 decay), there is about 40% decrease in the p_T integrated v_2 of photons relative to those from π^0 for $\sqrt{s_{NN}} = 7.7$ GeV to 2.76 TeV. From a simple modeling of the finite efficiency and purity of the counted photon sample, we find efficiency has negligible effect on the measured v_2 , however smaller purity tends to increase the v_2 of inclusive photon. The later is because of the charged hadrons, which acts as a source of contamination, are expected to have a higher v_2 than those from photons.

We find that the existing measurements of inclusive photon v_2 at RHIC energy of $\sqrt{s_{NN}} = 200$ GeV is best explained using AMPT-SM, while results from the AMPT default and UrQMD are smaller. This indicates that partonic interactions are relevant for generation of v_2 even at rapidities away from midrapidity at top RHIC energy. Such contributions appear to be much smaller at SPS energies, seen from the comparison of v_2 data to AMPT default and UrQMD models. Comparison of the centrality dependence of inclusive photon v_2 at SPS and RHIC energies to AMPT-SM model calculations with different partonic cross sections of 3, 6 and 10 mb, indicates that the data seems to favor a partonic cross section of 10 mb at both the energies.

We have provided the expected inclusive photon v_2 values at RHIC BES energies using the transport models. The AMPT default and UrQMD models give smaller v_2 compared to AMPT-SM, they also predict that the hadronic interactions at forward rapidities may not be sufficient to generate substantial inclusive photon v_2 at $\sqrt{s_{NN}} = 7.7$ GeV. The AMPT-SM model predicts that we should observe a longitudinal scaling in inclusive photon v_2 from RHIC BES to LHC energies provided the parton-parton cross section is independent of beam energy. A different parton-parton cross section will lead to breaking of the longitudinal scaling in v_2 .

Acknowledgments

We thank Zi-Wei Lin for useful discussions on AMPT model results and members of STAR collaboration for discussion on data presented. Financial assistance from the Department of Atomic Energy, Government of India is gratefully acknowledged. This work is supported by the DAE-BRNS project sanction No. 2010/21/15-BRNS/2026.

- [1] STAR Collaboration, J. Adams *et al.*, Phys. Rev. Lett. **95**, 122301 (2005); PHENIX Collaboration, A. Adare *et al.*, Phys. Rev. Lett. **98**, 162301 (2007).
- [2] J. Y. Ollitrault, Phys. Rev. **D 46**, 229 (1992); H. Sorge, Phys. Rev. Lett. **78**, 2309 (1997).
- [3] P. Huovinen, P. F. Kolb, U. Heinz, P. V. Ruuskanen, and S.A. Voloshin, Phys. Lett. **B503**, 58 (2001).
- [4] PHOBOS Collaboration, B. B. Back *et al.*, Phys. Rev. Lett. **94**, 122303 (2005).
- [5] Md. Nasim *et al.*, Phys. Rev. **C 83**, 054902 (2011).
- [6] B. Mohanty (for the STAR Collaboration), arXiv:1106.5902; STAR Collaboration, B. I. Abelev *et al.*, Phys. Rev. **C 81**, 024911 (2010).
- [7] M. M. Aggarwal *et al.*, Nucl. Instrum. Meth **A 499**, 751 (2003).
- [8] ALICE Collaboration, K. Aamodt *et al.*, JINST **3**, S08002 (2008).
- [9] WA93 Collaboration, M.M. Aggarwal *et al.*, Phys. Lett. **B 403**, 390 (1997).
- [10] S. A. Voloshin, A. M. Poskanzer and R. Snellings, arXiv:0809.2949; S. Voloshin, Y. Zhang, Z. Phys. **C 70**, 665 (1996).
- [11] S. A. Bass *et al.*, Prog. Part. Nucl. Phys. **41** 255 (1998); M. Bleicher *et al.*, J. Phys. G **25** 1859

- (1999).
- [12] Zi-Wei Lin, C. M. Ko, Phys. Rev. **C 65**, 034904 (2002); Zi-Wei Lin *et al.*, Phys. Rev. **C 72**, 064901 (2005).
- [13] STAR Collaboration, J. Adams *et al.*, Phys. Rev. Lett. **95**, 062301 (2005); Phys. Rev. **C 73**, 034906 (2006); B. I. Abelev *et al.*, Nucl. Phys. **A 832**, 134 (2010).
- [14] WA98 Collaboration, M. M. Aggarwal *et al.*, Nucl. Phys. **A 762**, 129 (2005); Eur. Phys. J **C 41**, 287 (2005).
- [15] R. Raniwala (For the STAR Collaboration), J. Phys. G **35**, 104104 (2008).
- [16] PHENIX Collaboration, S. S. Adler *et al.* , Phys. Rev. Lett. **96**, 032302 (2006).
- [17] X. N. Wang and M. Gyulassy, Phys. Rev. D **44**, 3501 (1991).
- [18] J. Xu and C. M. Ko, Phys. Rev. **C 83**, 034904 (2011).
- [19] ALICE Collaboration, K. Aamodt *et al.*, Phys. Rev. Lett. **105**, 252302 (2010)
- [20] BRAHMS Collaboration, I. G. Bearden *et al.*, Phys. Rev. Lett. **94**, 162301 (2005).
- [21] PHOBOS Collaboration, B. Alver *et al.*, Phys. Rev. Lett. **98**, 242302 (2007); B. Alver and G. Roland, Phys. Rev. **C 81**, 054905 (2010).
- [22] S. Gupta *et al.*, Science **332**, 1525 (2011); B. Mohanty, New J. Phys. **13**, 065031 (2011); B. Mohanty, Nucl. Phys. **A 830**, 899c (2009).
- [23] PHOBOS Collaboration, B. B. Back *et al.*, Phys. Rev. Lett. **91**, 052303 (2003).
- [24] BRAHMS Collaboration, I. G. Bearden *et al.*, Phys. Rev. Lett. **88**, 202301 (2002).
- [25] Md. Nasim *et al.*, Phys. Rev. **C 82**, 054908 (2010).